

半闭弯尾姬蜂寄生及其毒液对小菜蛾幼虫血细胞吞噬作用的影响

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摘要: 半闭弯尾姬蜂 *Diadegma semiclausum* 是小菜蛾 *Plutella xylostella* 的优势内寄生蜂, 拥有毒液、多分 DNA 病毒 (PDV) 等寄生因子, 能有效调控寄主幼虫的营养生理和免疫系统, 但其毒液在这过程中的功能不明。本文利用 SDS-PAGE 方法分析了半闭弯尾姬蜂毒液的蛋白组分, 利用寄主幼虫血细胞体外原代培养的方法, 研究了小菜蛾幼虫血细胞噬菌能力在半闭弯尾姬蜂寄生后的变化情况。结果表明: 半闭弯尾姬蜂毒液蛋白分子量主要集中在 35 ~ 220 kDa 之间, 少数小于 15 kDa, 但分子量处于 35 ~ 70 kDa 之间的蛋白含量较高, 与其他寄生蜂毒液蛋白相似。半闭弯尾姬蜂毒液单独对寄主小菜蛾幼虫功能血细胞 (浆血细胞和颗粒血细胞) 的延展能力和吞噬功能不产生破坏作用。但半闭弯尾姬蜂寄生后短时间内, 寄主功能血细胞的延展受到抑制, 然而功能血细胞仍然能识别外源异物, 却无法进一步吞噬外源物; 寄生后 24 h, 功能血细胞的延展力恢复, 颗粒血细胞的吞噬作用可顺利完成。本研究证明了半闭弯尾姬蜂寄生能暂时性地抑制颗粒血细胞的延展性从而影响其噬菌过程。

关键词: 半闭弯尾姬蜂; 小菜蛾; 寄生; 毒液; 多分 DNA 病毒; 血细胞; 血细胞延展; 吞噬作用

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Effect of parasitism by *Diadegma semiclausum* (Hymenoptera: Ichneumonidae) and its venom on the phagocytic ability of hemocytes from *Plutella xylostella* (Lepidoptera: Plutellidae) larvae

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Abstract: *Diadegma semiclausum* Hellen is a larval endoparasitoid of the diamondback moth, *Plutella xylostella* L. The parasitoid regulates its host physiology and development mediated by its maternal secretions, such as venom and polydnavirus (PDV), but the possible functions of venom of this PDV-producing endoparasitoid are unknown. The SDS-PAGE analysis of venom showed that the most protein bands ranged from 35 to 220 kDa with a few bands less than 15 kDa, but the most abundant bands were within 35–70 kDa, which were similar to venom proteins in other parasitoid-host systems. By *in vitro* primary-culture of host hemocytes with parasitoid venom fluid or *Escherichia coli*, the changes of spreading and phagocytic abilities of hemocytes from the parasitized or the non-parasitized host larvae indicated that the venom of *D. semiclausum* alone was harmless to the spreading and phagocytic abilities of plasmatocytes and granulocytes in larvae of the diamondback moth. However, the spreading ability of hemocytes from host larvae was obviously inhibited in the early stage of parasitism by *D. semiclausum*, but these hemocytes could still recognize the pathogens with a lapse of endocytosis; at 24 h post-parasitization, the hemocytes recovered their spreading ability and then granulocytes acted as phagocytes to engulf bacteria successfully. This study demonstrates that the parasitism of *D. semiclausum* can affect the phagocytosis of hemocytes from its host larvae through inhibiting the spreading ability of granulocytes.

Key words: *Diadegma semiclausum*; *Plutella xylostella*; parasitism; venom; polydnavirus (PDV); hemocyte; hemocyte spreading; phagocytosis

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吞噬作用是一种通过信号触发而引起的一系列细胞膜活动,是最重要的细胞功能之一(Strand, 2008)。单细胞生物通过吞噬摄取外界的营养物质,而多细胞生物则通过吞噬作用参与胚胎发育过程和体内针对病原物的免疫过程(Lavine and Strand, 2002)。对昆虫而言,血细胞的吞噬作用更是免疫系统的重要组成部分(Hoffmann, 1995; Strand, 2008)。在吞噬过程中,首先是功能细胞表面受体识别外源异物并将此信号向胞内传递,引起胞膜的活化,使细胞骨架发生重构,细胞以伪足伸出的形式进行延展从而执行吞噬(de Winter *et al.*, 2007)。在寄主-寄生蜂系统中,寄主血细胞吞噬功能的变化被认为是寄生蜂调控寄主免疫生理的主要手段之一(Li and Webb, 1994; Strand *et al.*, 2006)。

毒液是寄生蜂影响及调控寄主生理的基本因子之一,能够与其他寄生因子,如多分 DNA 病毒(polydnavirus, PDV)等一起在寄生时进入寄主体内。毒液能够单独或在其他寄生因子的协助下麻痹寄主、影响寄主生长发育或者破坏寄主免疫系统(Beckage and Gelman, 2004)。不同寄生蜂体内毒液的成分及功能不同,这与寄生蜂本身所处的系统地位、寄生习性和寄主范围等相关(Moreau and Guillot, 2005)。迄今为止,有关于寄生蜂毒液的研究大多集中于外寄生蜂,其功能主要是导致寄主麻痹或死亡,从而方便幼蜂摄取寄主营养以完成个体发育(Weaver *et al.*, 2001)。有关于内寄生蜂毒液的研究,特别是毒液作为独立因子调控寄主生理的研究相对较少且零散(Asgari, 2006)。目前,大部分研究认为具有 PDV 的内寄生蜂在调控寄主免疫反应的过程中,起主要作用的是 PDV 而不是毒液(Beckage, 1998; Asgari, 2006)。内寄生蜂毒液的功能主要是协助 PDV 或其他寄生因子对寄主的生理进行调控(Moreau and Guillot, 2005),如毁侧沟茧蜂 *Microplitis demolitor* 的毒液单独不能对其寄主造成任何影响,但是却能对 PDV 起到增效作用(Strand and Dover, 1991)。然而,也有研究表明,内寄生蜂的毒液具有一定的单独行使功能的能力,如高浓度的菜蛾盘绒茧蜂 *Cotesia vestalis* 毒液能够在短时间内抑制寄主小菜蛾幼虫血细胞的延展能力(Yu *et al.*, 2007)。事实上,内寄生蜂毒液在内寄生蜂调控寄主的过程中发挥了众多作用(表 1)(Asgari, 2006)。

半闭弯尾姬蜂 *Diadegma semiclausum* Hellen 是小菜蛾 *Plutella xylostella* L. 的优势内寄生蜂(Waterhouse, 1992),拥有 PDV 和毒液等寄生因子

(Huang *et al.*, 2008b),能够对寄主小菜蛾的营养生理和免疫系统进行有效的调控(Huang *et al.*, 2008a, 2009)。但是关于半闭弯尾姬蜂毒液的功能却鲜有报道。目前已有研究表明,半闭弯尾姬蜂寄生能够减少被寄生小菜蛾幼虫体内的血细胞数量,细胞的延展和包裹作用也暂时受到抑制,但经过一段时间后可恢复(Huang *et al.*, 2009)。但并无研究内容涉及血细胞吞噬功能的变化,也不涉及单独寄生因子对此过程的调控研究。本文在此基础上,就半闭弯尾姬蜂毒液对寄主血细胞的延展行为及吞噬作用的影响展开研究,期望可以进一步明确半闭弯尾姬蜂调控寄主小菜蛾血细胞免疫的生理机制。

1 材料与方法

1.1 供试虫源

小菜蛾在控光(14L:10D, 光照强度 > 1 000 lx)、控温($22 \pm 1^\circ\text{C}$)、控湿(相对湿度 60% ~ 80%)的养虫室或智能人工气候箱内饲养。按李广宏等(1995)的方法,以 20% 的蜂蜜水饲养成蛾,盆栽甘蓝饲养幼虫。半闭弯尾姬蜂采自郑州郊区,在控光、温、湿的人工气候室内,参照陈宗麒等(2003)方法进行繁殖及续代,成蜂供给 10% 的蜂蜜水。

小菜蛾 2 龄幼虫大小及生理状态具有高度的一致性,因此为保证实验中处理与对照的可比性,试虫均采用刚进入 3 龄的幼虫,即先挑取 2 龄末幼虫,待其蜕皮后用于寄生。

采用“单头单管寄生”的方法寄生供试的小菜蛾幼虫,具体操作如下:在一支长 8 cm、直径 1.5 cm 的小试管内引入羽化 2 d 已交配过的雌蜂 1 头,然后用毛笔挑取小菜蛾幼虫 1 头放入管内,观察产卵行为发生一次后用毛笔移出幼虫,换另 1 头未寄生的幼虫重复操作。将寄生过的小菜蛾幼虫接到事先准备好的叶片或盆菜上饲养,用于实验。

1.2 小菜蛾血细胞原代培养

小菜蛾幼虫在 -20°C 冷冻麻痹,依次用 75% 的酒精和 PBS(pH 7.4)清洗体表并在滤纸上擦干后,在 Parafilm 膜上用灭菌后眼科剪剪去幼虫的腹足,待血淋巴自然流出后用无菌毛细管吸取并加入到预先添加昆虫血细胞培养基的 96 孔板中,在 25°C 下孵育。

1.3 毒液收集及毒液蛋白初步分析

收集半闭弯尾姬蜂雌蜂,活体条件下封冻于 -80°C ,2 周内集齐 100 头雌蜂然后进行解剖收取毒液。解剖时,解冻雌蜂并依次用 75% 的酒精、PBS(pH 7.4)清洗体表并在滤纸上吸干后,冰上解

表 1 含 PDVs 的寄生蜂毒液对寄主的生理作用
Table 1 Functions of venoms from parasitoids involved with PDVs

寄生蜂 Parasitoids	毒液的生理作用 Functions of venom	参考文献 References
黑唇姬蜂 <i>Campoletis sonorensis</i>	参与破坏浆血细胞和颗粒血细胞骨架 Involved in alteration of plasmatocyte and granulocyte cytoskeletons	Webb and Luckhart, 1994
黑头折脉茧蜂 <i>Cardiochiles nigriceps</i>	协同 PDVs 抑制前胸腺活性 Depression of thoracic gland activity with PDVs	Tanaka and Vinson, 1991
棉大卷叶螟甲腹茧蜂 <i>Chelonus inanitus</i>	抑制蜕皮激素分泌 Inhibition of host ecdysteroid secretion	Grossniklaus-Bürgin <i>et al.</i> , 1998
集聚绒茧蜂 <i>Cotesia congregata</i>	参与抑制包囊 Involved in inhibiting encapsulation of host hemocytes	Lavine and Beckage, 1996
菜粉蝶盘绒茧蜂 <i>Cotesia glomerata</i>	协同 PDVs 抑制蜂卵被包囊 Involved in preventing encapsulation of the parasitoid egg with PDVs	Wago and Tanaka, 1989
粘虫盘绒茧蜂 <i>Cotesia kariyai</i>	参与抑制包囊 Involved in inhibition of encapsulation by host hemocytes	Tanaka, 1987
	抑制性腺细胞发育 Retardation of testis development	Yagi and Tanaka, 1992
	影响寄主营养代谢 Regulate the host metabolic efficiency	Nakamatsu <i>et al.</i> , 2001
	提高寄主保幼激素滴度 Increase in host juvenile titres	Wani <i>et al.</i> , 1990
黑腿茧蜂 <i>Cotesia melanoscela</i>	协助 PDVs 侵染寄主组织 Promotion of uncoating <i>in vitro</i> and persistence <i>in vivo</i> of PDVs	Stoltz <i>et al.</i> , 1988
微红绒茧蜂 <i>Cotesia rubecula</i>	抑制寄主血淋巴酚氧化酶酶活 Inhibition of host hemolymph phenoloxidase activity	Asgari <i>et al.</i> , 2003
菜蛾盘绒茧蜂 <i>Cotesia vestalis</i>	暂时抑制寄主血细胞免疫反应 Temporal inhibition of host cellular immune responses	Yu <i>et al.</i> , 2007
	与 PDVs 协同提高寄主解毒酶系统活性 Involved in enhancing detoxifying enzyme activity with PDVs	Takeda <i>et al.</i> , 2006
红足侧沟茧蜂 <i>Microplitis croceipes</i>	抑制寄主发育 Inhibition of host growth	Gupta and Ferkovich, 1998
黑头异脉茧蜂 <i>Toxoneuron nigriceps</i>	降低前胸腺分泌活性 Depression of thoracic gland activity	Tanaka and Vinson, 1991
	协助 PDVs 表达 Involved in expression of PDVs	Zhang <i>et al.</i> , 2004b
	抑制包囊 Prevention of encapsulation by host hemocytes	Zhang <i>et al.</i> , 2006

剖雌蜂，收集毒腺，撕破毒囊，使毒液释放到 20 μ L PBS 中，-80℃ 贮藏或直接进行实验。

Bradford 方法测蛋白毒囊内蛋白含量。SDS-PAGE 分析蛋白组分，电泳条件为：12% 的分离胶，2.5% 浓缩胶，电极缓冲液为 Tris-甘氨酸电极缓冲液系统；电泳电压 80 V。

1.4 毒液对血细胞延展能力的影响

在原代培养的未寄生小菜蛾幼虫血细胞培养液中加入毒液，使培养液中的毒液浓度分别达到 0.01, 0.02, 0.04, 0.06, 0.08 和 0.1 当量/ μ L；每个浓度设 5 个重复，分别于 1 h 和 4 h 后置于 Leica 倒置显微镜 (Leica DMIRB) 下观察浆血细胞和颗粒血细胞的延展行为，浆血细胞变为梭形或其他不规则形状则判为延展，颗粒血细胞以伸出伪足为延展，两种细胞均以圆形为未延展。

1.5 半闭弯尾姬蜂寄生及毒液对血细胞噬菌能力的影响

大肠杆菌 *Escherichia coli* 的异硫氰酸荧光素 (fluorescein-5-isothiocyanate, FITC) 标记方法参考

Beck 和 Strand (2005)。将热灭活的大肠杆菌放入 0.5% 含 FITC (0.1 mg/mL) 的碳酸缓冲液 (pH 9.5)，使其终浓度达到 10^9 /mL，置于 37℃ 培养 30 min 后，用磷酸缓冲液清洗菌体直至上清不含 FITC 为止，于 -20℃ 贮存。

噬菌作用具体试验步骤如下：100 μ L 细胞培养基中加入苯基硫脲 (phenylthiourea, PTU) (0.02%)，加入 1 头小菜蛾的血淋巴，25℃ 培养 30 min 后，加入 FITC 标记的大肠杆菌，大肠杆菌与血细胞的数量比在 15:1 ~ 30:1 之间；25℃ 中放置 2 ~ 3 h 后在荧光倒置显微镜 (Leica DMIRB) 下观察血细胞的噬菌状况。试验分 2 组处理：处理 I 为半闭弯尾姬蜂寄生 (即包含毒液和 PDVs 等的所有寄生因子) 对小菜蛾幼虫血细胞噬菌能力的影响，样品取自寄生后 1 h 和 24 h 的小菜蛾幼虫，分别设 5 个重复；处理 II 为毒液对血细胞噬菌能力的影响，样品为未被寄生的小菜蛾幼虫血淋巴，并在培养液中加入梯度浓度的毒液，分别为 0.01, 0.02, 0.04, 0.06, 0.08 和 0.1 当量/ μ L，每个浓度设 5 个重复。

2 结果

2.1 半闭弯尾姬蜂毒液内蛋白浓度及蛋白组分

单头半闭弯尾姬蜂毒液囊中蛋白含量为 $0.106 \pm 0.016 \mu\text{g}$ 。通过 SDS-PAGE 电泳分析, 半闭弯尾姬蜂毒液中大部分蛋白的分子量集中在 35 ~ 220 kDa 之间, 其中分子量在 35 ~ 70 kDa 之间的几种小分子蛋白的含量相对较高; 同时, 在电泳图中也出现了少数分子量小于 15 kDa 的小肽(图 1)。

2.2 毒液对血细胞延展能力的影响

为了明确毒液的功能, 本试验将正常小菜蛾血细胞提取后进行体外培养, 同时在培养液中加入不同浓度的毒液。结果表明, 小菜蛾血细胞能够在含有 0.01 ~ 0.1 当量/ μL 毒液的培养液中正常延展; 且随着培养时间的延长, 血细胞的延展能力不受到影响(图 2)。

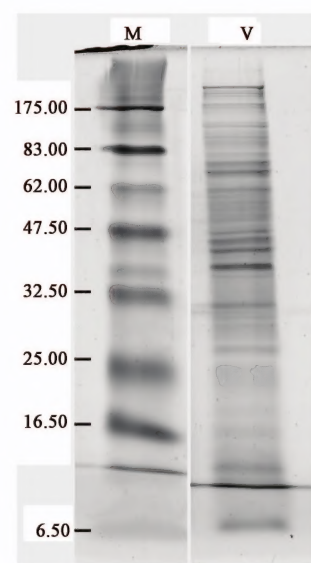


图 1 半闭弯尾姬蜂毒液蛋白的 SDS-PAGE 电泳图

Fig. 1 SDS-PAGE analysis of venom proteins from *Diadegma semiclausum*

M: 标准分子量蛋白 Protein marker; V: 毒液 Venom.

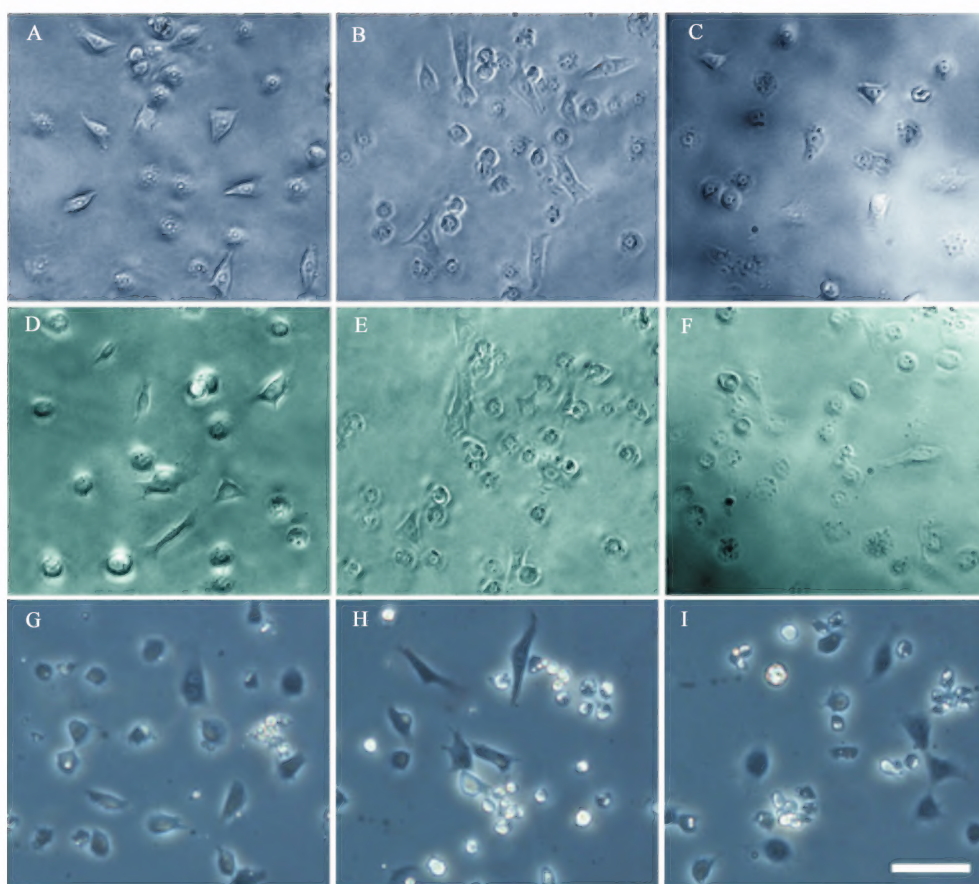


图 2 半闭弯尾姬蜂毒液对小菜蛾幼虫血细胞延展能力的影响

Fig. 2 Effect of *Diadegma semiclausum* venom on the spreading ability of hemocytes from *Plutella xylostella* larvae *in vitro*

A, B, C, G, H, I: 浓度分别为 0.01, 0.02, 0.04, 0.06, 0.08 和 0.1 当量/ μL 的毒液处理 1 h (1 h incubation with 0.01, 0.02, 0.04, 0.06, 0.08 and 0.1 venom reservoir equivalent/ μL of venom added, respectively); D, E, F: 浓度分别为 0.01, 0.02, 0.04 当量/ μL 的毒液处理 4 h (4 h incubation with 0.01, 0.02 and 0.04 venom reservoir equivalent/ μL of venom added, respectively). 标尺 Bars = 0.05 mm.

2.3 毒液对血细胞噬菌能力的影响

在含有不同浓度(0.04, 0.06, 0.08 和 0.1 当量/ μL)半闭弯尾姬蜂毒液的培养液中进行小菜蛾幼虫血细胞的培养,同时也加入足量的经 FITC 标记的大肠杆菌。结果显示,即使培养液中含有较高浓度的半闭弯尾姬蜂毒液,但小菜蛾颗粒血细胞仍然能够顺利地吞噬大量的大肠杆菌(图 3)。

2.4 寄生对寄主血细胞噬菌能力的影响

半闭弯尾姬蜂寄生时会将毒液、PDV 及 萼液蛋白等寄生因子同时注入小菜蛾幼虫血腔内。将寄生

后 1 h 的寄主幼虫血细胞取出后进行体外培养,结果发现几乎所有的颗粒血细胞和浆血细胞都不能延展,无法如对照细胞一般伸出明显的伪足,而呈现圆饼状(图 4: A)。虽然图 4(A)中的颗粒血细胞无法发生延展,但是,其细胞膜周围却附着着大量的大肠杆菌,然而附着在胞膜表面的大肠杆菌并没有被进一步吞噬进入细胞内(图 4: B)。半闭弯尾姬蜂寄生后 24 h 的小菜蛾幼虫血细胞能够正常延展,如图 4(C)所示。从图中可以看到,浆血细胞伸出明显长且不规则的伪足,而颗粒血细胞的伪足则相

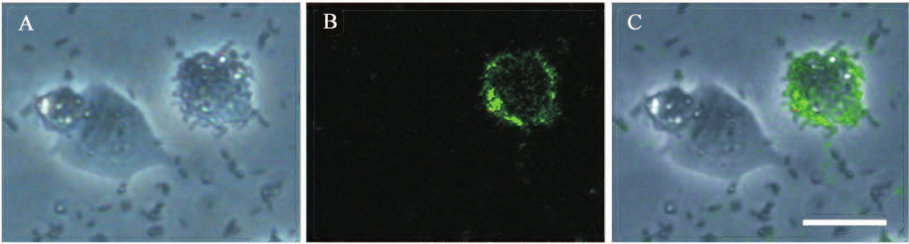


图 3 半闭弯尾姬蜂毒液(0.1 当量/ μL)对小菜蛾幼虫血细胞噬菌能力的影响

Fig. 3 Effect of *Diadegma semiclausum* venom (0.1 venom reservoir equivalent/ μL) on the phagocytosis of hemocytes from *Plutella xylostella* larvae in vitro

A: 光镜照片 Light microscopic photo; B: 荧光照片, 图为 FITC 标记的大肠杆菌 Fluorescent microscopic photo of FITC-labeled *Escherichia coli*; C: 照片 A 和 B 的叠加 Photos A and B merged. 标尺 Bars = 0.02 mm.

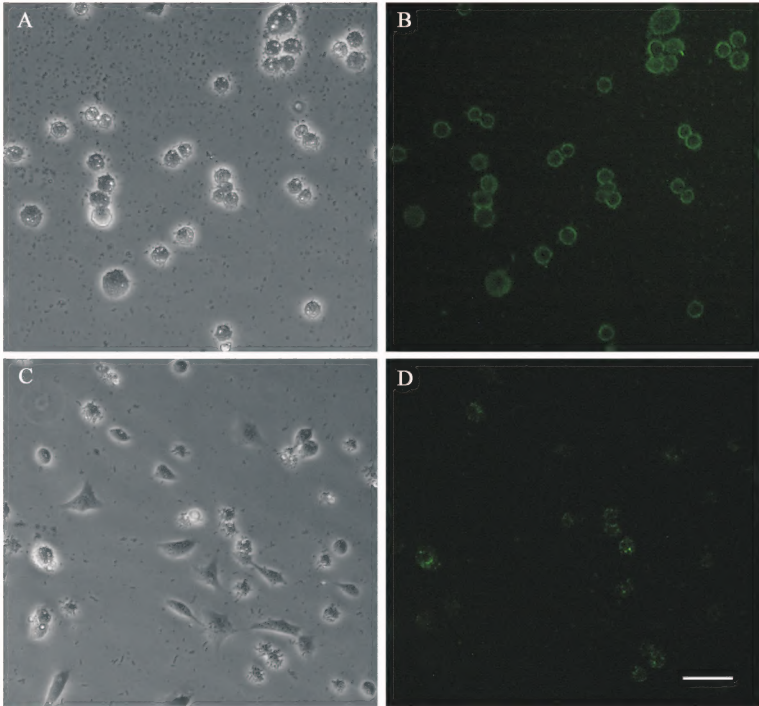


图 4 半闭弯尾姬蜂寄生对寄主小菜蛾幼虫血细胞噬菌能力的影响

Fig. 4 Effect of parasitization of *Diadegma semiclausum* on phagocytosis of hemolymph from *Plutella xylostella* larvae in vitro

A: 半闭弯尾姬蜂寄生后 1 h 的寄主小菜蛾幼虫血细胞的光镜照片 Light microscopic photo of hemocytes from *P. xylostella* larvae at 1 h post-parasitization; B: 照片 A 视野的荧光照片 Florescent microscopic photo of photo A vision; C: 半闭弯尾姬蜂寄生后 24 h 的寄主小菜蛾幼虫血细胞的光镜照片 Light microscopic photo of hemocytes from *P. xylostella* larvae at 24 h post-parasitization; D: 照片 C 视野的荧光照片 Florescent microscopic photo of photo C vision. 标尺 Bars = 0.05 mm.

对较短且密;同时,在发生延展的颗粒血细胞的胞质内可以明显地观察到发出荧光的亮点,即经过 FITC 标记的大肠杆菌(图 4:D)。

3 讨论

毒液是寄生蜂与寄主协同进化的结果,在调节寄主发育、保证寄生蜂成功寄生中发挥着非常重要的作用(Quicke, 1997)。研究发现,大部分寄生蜂毒液蛋白分子量都比较大(Moreau and Guillot, 2005),如近曲斑甲腹茧蜂 *Chelonus* sp. near *curvimaculatus* (Leluk and Jones, 1989)、麦蛾茧蜂 *Bracon hebetor* (Quistad et al., 1994) 和菜粉蝶绒茧蜂 *Cotesia glomeratus* (Leluk et al., 1989) 毒液中的蛋白分子量分别不低于 30, 20 和 18 kDa。但是也有一些寄生蜂的毒液中存在小分子多肽,如东方旋小蜂 *Eupelmus orientalis* (Doury et al., 1997)、瘤姬蜂 *Pimpla hypochondriaca* (Dani et al., 2003)、缩基反颚茧蜂 *Asobara tabida* (Moreau et al., 2004)、微红绒茧蜂 *Cotesia rubecula* (Zhang et al., 2004a) 和颈双缘姬蜂 *Diadromus collaris* (酈卫弟等, 2006) 等毒液中发现了分子量小于 10 ~ 15 kDa 的多肽。半闭弯尾姬蜂毒液蛋白的分子大小具备寄生蜂毒液的特点,既有大于 100 kDa 的大分子蛋白,也含有个别小于 15 kDa 的小分子蛋白,但大部分蛋白的大小处于 35 ~ 70 kDa 之间,这与其他寄生蜂的毒液蛋白的分布比例(按分子量大小)相似,如黄腹潜蝇茧蜂 *Opius caricivora* 的毒液中 20.1 ~ 43.5 kD 的蛋白带含量最高(万志伟等, 2005),蝶蛹金小蜂 *Pteromalus puparum* 和丽蝇蛹集金小蜂 *Nasonia vitripennis* (Zhang et al., 2005) 以及颈双缘姬蜂 *D. collaris* (酈卫弟等, 2006) 等寄生蜂毒液中含有较高的蛋白也处于近似的范围内。而且,大部分从寄生蜂毒液中分离得到的功能蛋白组分,其分子大小也集中在这个范围内(Beckage and Gelman, 2004),如黑头折脉茧蜂 *Cardiochiles nigriceps* 毒液中含一种大小为 66 kDa 的蛋白,可延长寄主幼虫的发育历期(Tanaka and Vinson, 1991);微红绒茧蜂 *C. rubecula* 毒液中含有一种为 50 kDa 的蛋白,则可以抑制寄主血淋巴的黑化(Asgari et al., 2003)。通过与其他寄生蜂毒液的蛋白条带比较,推测半闭弯尾姬蜂毒液也可能含有具备调控寄主生理作用的功能蛋白。

Huang 等(2009, 2010)研究证明,小菜蛾幼虫

体内有延展能力的血细胞为颗粒血细胞和浆血细胞,但具有噬菌作用的血细胞只有颗粒血细胞。半闭弯尾姬蜂自然寄生小菜蛾幼虫时,在寄生后短时间内可抑制血细胞的延展性,但当寄生后 24 h,血细胞的延展能力又可得到恢复(Huang et al., 2009)。本文结果再次证实了这一结论,同时发现虽然在寄生后 1 h 内颗粒血细胞没有延展,但其表面仍能够粘附大量的大肠杆菌但却未进行进一步的吞噬作用;寄生后 24 h,当血细胞可延展时,噬菌作用也可顺利进行。比较分析以上两个现象,可以说明具有噬菌功能的颗粒血细胞表面的外源物识别受体并没有受到寄生因子的破坏,但因血细胞的细胞膜无法延展而进行重构内陷,从而阻碍了噬菌过程的完成。因此,半闭弯尾姬蜂寄生通过暂时性地抑制寄主颗粒血细胞的延展性从而影响其噬菌过程。Huang 等(2009)研究表明,半闭弯尾姬蜂寄生后短时间内小菜蛾幼虫功能血细胞无法进行包裹的主要原因之一是血细胞延展力受到抑制,而本文结果则再次证实暂时性抑制血细胞延展是半闭弯尾姬蜂寄生调控小菜蛾幼虫细胞免疫的主要机制之一。

寄生蜂毒液一旦进入寄主血腔即开始行使功能,然而这种功能的发挥不能持续很长时间(Moreau and Guillot, 2005)。因此,为了探求毒液是否影响或参与影响颗粒血细胞的噬菌作用,本文设计了在血细胞的培养基中加入毒液后观察颗粒血细胞噬菌功能反应的试验,结果表明毒液单独对血细胞的延展性和颗粒血细胞的噬菌功能不产生任何影响。这一结果与其他大部分内寄生蜂的毒液性质一样,即目前尚未发现半闭弯尾姬蜂毒液具备单独影响血细胞功能的能力。然而,半闭弯尾姬蜂毒液是否与其他内寄生蜂的毒液一样具有协助 PDV 的功能,将有待于进一步研究。

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